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Assessment of hybrid renewable power sources for rural electrification in Malaysia

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ABSTRACT

Research works on hybrid renewable energy systems for rural electrifications have been quite intensive in recent years. Traditional power systems for remote or rural areas are based on fossil fuels. After addition of renewable energy resources, solar energy applications have become popular in remote energy systems. The recent study and research works show that adding other possible renewable energy resources such as wind, hydro and biomass could make a hybrid system more cost-effective and environmentally friendly. Hence, in the present study, an overview of applied hybrid renewable energy system (HRES) for worldwide villages with special attention on Malaysia has been proposed to help present and future works for better achievement in this field. Furthermore, a proper design and analysis for one village in Malaysia based on proposed combination is provided. The results show that combination of photovoltaic-wind -battery is defined as a cost-effective HRES for villages in Malaysia.

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1. Introduction

Approximately twenty percent of global population or 1.3 billion people are living without electricity in the world. In developing countries in Asia, the percentage is around 36% of the total population. Furthermore, the number of people without access to the electricity will remain high at around 16% of total by 2030 [1]. Thus, rural electrification with the proper energy system in this part of Asia is an urgent issue in the energy sector [2].

Although the first solution for rural electrification is the extending of national grid by power transmission line, but in some cases it is not a possible solution [3]. According to the World Bank, grid extension prices vary from $6340/km in a densely populated country to $19,070/km in other countries [4]. Hence, the

Abbreviations: RE, renewable energy; PV, photovoltaic; RES, renewable energy system; HRES, hybrid renewable energy system; RETs, renewable energy technologies; HOMER, hybrid optimization model for electric renewable; HOGA, hybrid optimization by genetic algorithms

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off-grid power system offers an effective solution. The conventional method of local generation uses diesel generator that is not environmentally-friendly. Therefore, as an improved model of local energy generation, stand-alone renewable energy system with cleaner energy has been proposed [5]. In previous decade, the application of stand-alone renewable energy (RE) systems has increased steadily as a suitable solution for rural areas.

In recent years, researchers have focused on a more reliable RE system to combine with many sources of renewable energies to form a single system, which is called a hybrid renewable energy system (HRES).The reliability and cost of energy have improved in this combined units due to availability of many sources of energy to support each other in a cost-effective way [6]. For example, when solar energy is not available at night, wind source is a suitable support and while many sources of energy are available, choosing the source with lower cost of energy is preferable. Furthermore, the life time of battery bank in HRES can be increased as compared to single renewable energy system (Fig. 1). The PV panels and wind turbines produce the DC power and the diesel generator is connected to the DC line by using a rectifier.

Malaysia is chosen as a study case of this work and summary of Malaysia's plan for HRES in both application and research parts for rural areas is included in this article. Referring to the Tenth Malaysia Plan, the percentage of villages without electricity coverage was 0.5% to 33% in various territories of country in 2009. It is expected that 100% coverage of electricity in Peninsular Malaysia and 99% in Sabah and Sarawak can be achieved by 2015 as shown in Fig. 2. On the other side, the current focus of this country is to increase the share of renewable energy (RE) and reduce emission intensity [7].

In this paper, first a comprehensive overview of applied HRESs for stand-alone applications in the world with special attention to the Malaysia is presented. Second, according to the suggested combination for HRES by previous researchers in Malaysia, a hybrid renewable power system is designed and provided for a village in Malaysia.

2. Literature review

2.1. Rural electrification by HRESs

Whereas the stand-alone HRES design and performance depending on location and climate [8], the optimization of various

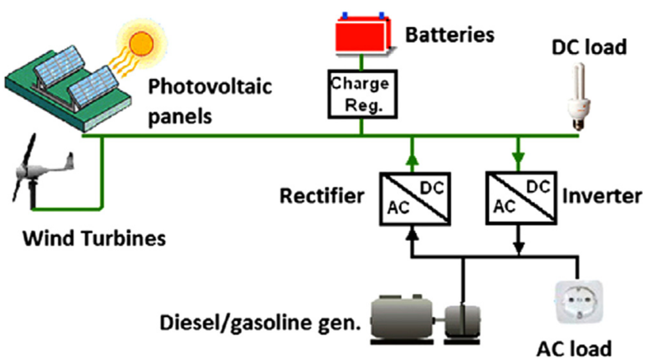


Fig. 1. PV–wind–diesel–battery HRES.

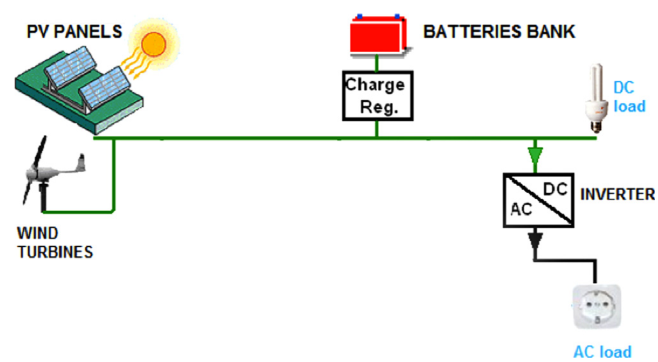
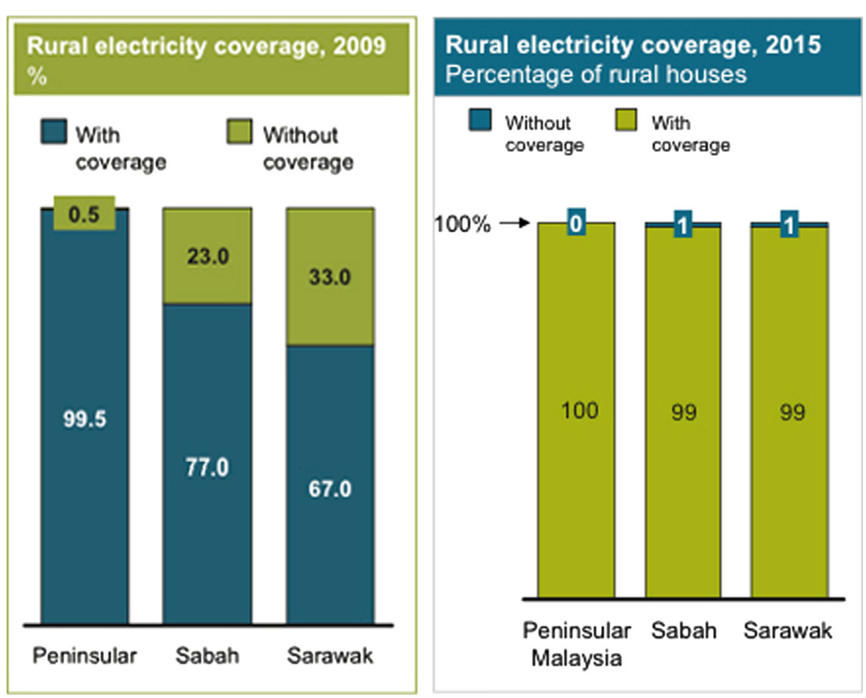


Fig. 3. Simulated model of PV–wind–battery system using iHOGA.



SOURCE: Ministry of Rural and Regional Development

Fig. 2. Rural electrification coverage for Malaysia in 2009 and 2015.

types of hybrid systems have to be discussed separately. Finding the suitable configuration of HRES are related to the topography of the location, potential of available energy resources and types of required energy [9]. Therefore, in this paper, the applied optimization and HRES for rural electrification are explained in different classifications as below:

2.1.1. Rural electrification by PV–wind–battery HRES

The PV–wind–battery HRES uses three power sources where each of them is capable to operate in stand-alone situation. The control strategy, which is important in hybrid system with more than one power sources, is used to check availability and connection of sources to the system and state of charge in batteries. The control strategy or dispatch strategy is defined in various classes as load following, cycled charging strategy and combined strategy [10]. Fig. 3 shows the model of the PV–wind–battery HRES by using HOGA software.

The DC to AC inverter is used to support the AC load and the battery is an essential storage part of this unit that sometimes works as a source of energy. Almost most of the storage systems applied for HRES is valve regulated lead acids (VRLA) due to low cost and availability of them. HRES with less than two energy sources such as PV–battery or wind–battery are not suitable for battery charging due to intermittent characteristics of renewable energies. Badejani [11] presented an effective methodology for design and modeling of hybrid wind-photovoltaic systems including their planning and analysis using discrete optimization of cost function and energy balance calculation.

Many researchers in recent years have worked on rural and remote electrifications by stand-alone hybrid systems. Shaahid in [12] evaluated off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia. Brent [13] comprised wind–solar and lead–acid battery energy storage technologies that were implemented as a mini-hybrid remote electrification system for the village in the Eastern Cape Province of South Africa. Naikodi in [14] examined solar–wind–battery hybrid power for rural Indian PV sites where antennas and electronic communications equipment are installed. Panahandeh et al. [15] simulated PV–wind hybrid systems combined with hydrogen storage for rural electrification in Essaouira region at the West coast of Morocco were done by HOMER.

There are some published articles that mention about progress and development of hybrid renewable systems for rural areas in Malaysia. In [16], Tamer Khatib presented a single optimization for hybrid PV–wind system based on loss of load probability and system cost for Kuala Terengganu, Malaysia. Daut [17] performed feasibility study of solar radiation and wind speed for photovoltaic and wind power hybrid generation in Perlis, Northern Malaysia. He suggested of adding wind energy to support hybrid system up to 10% of total output voltage in Perlis. Finally, Chong [18] analyzed techno-economic aspect of a wind–solar hybrid renewable energy system with rainwater collection feature for urban high-rise application in Malaysia. In this article, a small scale wind turbine is introduced as popular type of energy source in residential areas.

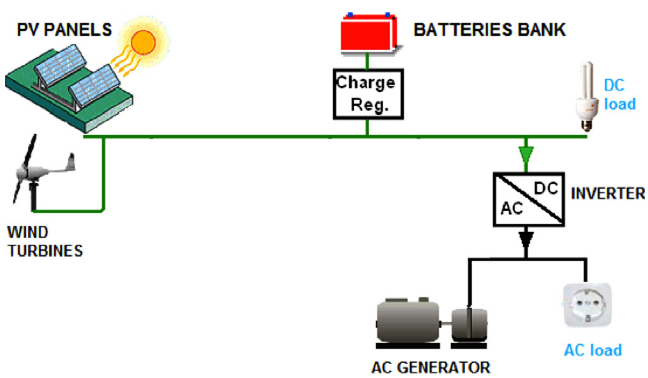


Fig. 4. Simulated model of PV–wind–diesel–battery system using iHOGA.

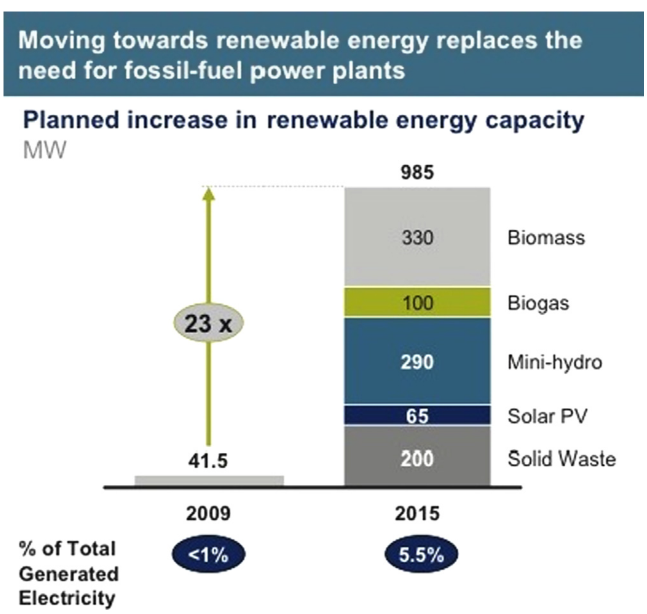


Fig. 5. Renewable energy plan for Malaysia.

2.1.2. Rural electrification by PV–wind–diesel–battery HRES

Although usage of diesel generator in a hybrid renewable energy system has not been environmental friendly, some researchers have suggested this source of energy to support reliability of HRES. Many researchers considered this type of system as an appropriate one for their design [19,5,20]. Fig. 4 shows the block diagram of a typical PV–wind–diesel–battery system.

Phuang pornpitak [21] analyzed the PV–diesel and PV–wind–diesel hybrid systems installed in Thailand. In [22], simulation and sizing of a PV–wind–diesel hybrid system with battery storage for

Table 1
Proposed appliances for one rural house.

Electric appliances	Power (Watts) per hour	Operating hour per day	Average usage (hour/day)	Usage for 1 unit per day (W h)	Number of units	Total usage for 1 house per day (kW/h)
Fluorescent light bulb	22	18 to 23	5	110	2	0.22
Refrigrator	120	from 0 to 24	8	960	1	0.96
TV	70	from 18 to 23	5	350	1	0.35
Fan	50	from 18 to 23 and 13 to 14 for lunch	6	300	1	0.30
Water pump	150	from 12 to 14	2	300	1	0.30
Total						**2.13**

rural electrification in four Algerian's sites is presented. Mondal et al. [23] analyzed wind–diesel generator-battery, wind-PV–diesel generator-battery, PV–diesel generator-battery hybrid and diesel generator systems for generating electricity in the rural areas of Bangladesh. Asrari in [24] discussed a hybrid PV–wind–diesel–battery system for Iran in a remote rural village in Binalood region, called Sheikh Abolhassan. Baghdadchi [25] explored wind–PV–diesel–battery hybrid power systems in rural Western New York. Finally, in [26], G.J. Dalton analyzed PV, wind, battery, diesel system for subtropical coastal area of Queensland, Australia.

For this hybrid system, there are two research works in Malaysia. Ngan [27] analyzed the potential utilization of hybrid photovoltaic–wind turbine–diesel with and without battery system in southern city of Malaysia, Johor Bahru. In [28], the authors introduced an implemented project for integrating power supply (PV–wind–diesel–battery) at Pulau Perhentian (Perhentian Island) in Malaysia.

2.1.3. Rural electrification by other HRESs

Although hydro power can be one of the energy sources with the lowest cost of energy in remote villages, but it is depended on availability and possibility. Kenfack [8] presented the size optimization model for micro hydro–PV–diesel–battery hybrid system in a village in Cameroon. Bakos [29] carried out operation of a hybrid wind-hydro power system to produce low cost electricity in the island of Ikaria in Greece.

In [30], the authors investigated the possibility of using a stand-alone solar-micro hydro HRES for low cost electricity production, that could meet the energy load requirements of an isolated rural area in Kwa-Zulu Natal in South Africa. Bekele [31] did a feasibility study of small hydro–PV–wind hybrid system for off-grid rural electrification in Ethiopia by using HOMER. Zhang Fan [32] optimized the configuration of wind–hydro–PV hybrid generating system in the rural area of China. Anjana [33] evaluated electrification by mini hybrid PV–solar–wind energy system for rural, remote and hilly/triple areas in Rajasthan (India).

Another point of view shows that the addition of biomass energy to hybrid system would be effective in some cases. Neto [34] introduced an alternative hybrid power system configuration combining biogas–PV hybrid power system for decentralized energy supply of rural areas. Gupta [35] designed a hybrid energy system which includes wind–photovoltaic–biomass and small-micro hydro to supply the load in Jaunpur of Uttaranchal state, India. However, there are some main issues for adding biomass to hybrid system as s source of energy. The first obstacle is defined as availability of fuel and continuous supply for such system [36]. The second major one is pollutions and emissions from burning biomass fuels [37,38].

Table 2
The best results of sizing optimization.

Numbers	PV modules	Wind turbines	Batteries
Number in parallel	20	0	1
Number in serial	2	1	24

There are a few works related to the combination of other types of HRES in Malaysia. In [39], the rural electrification study of the ICT Telecenter in Bario village in the Kelabit highland of Sarawak is presented. The authors in this article used HOMER to evaluate a hybrid diesel-solar-hydro-fuel cell energy schemes for the ICT Telecenter. Lau in [40] used HOMER and demonstrated that application of hybrid PV–diesel system with battery can significantly reduce the dependency on only diesel resource. In another work [16], the same hybrid system for Malaysia was evaluated. In [41], Martin Anyi considered solar, wind and micro-hydro for a village in Sarawak. In [42], a study on the technical aspects and life cycle costs of using a PV–diesel generator for a typical remote school with the example of Balleh National Secondary School in Sarawak is presented.

Taking into account information from the Tenth Malaysia Plan, Fig. 5 shows the increase in renewable energy application from 1% in 2009 to 5.5% of Malaysia's total electricity generated by 2015 [7].

3. Applied HRESs in Malaysia

Malaysia as an equatorial country has had a large amount of solar energy and various types of solar based system are implemented in this country [2]. Moreover, many works have been carried out for small scale applications of wind energy in Malaysia [43–45]. The researchers in these works concluded that although there is not much wind power for large grid-connected plant, but small scale stand-alone wind system is suitable for many locations in Malaysia. Malaysian energy provider, Tenaga Nasional Berhad (TNB), through an especial program for rural electrification by HRES, has installed many hybrid power stations in remote areas as listed below [46].

3.1. Langkawi cable car, middle station (PV–diesel)

Ali and Sopian in [47] presented the operation of installed PV–diesel hybrid system in Langkawi cable car. They concluded that

Table 4
Cost analysis of proposed system study case.

Components	Kampung Oapr	
	(€)	RM
Initial investment cost	33,450	133,800
PV panels costs	8,130	32,520
Wind turbines costs	6,687	26,748
Battery	28,286	113,144
Auxiliary components costs	2,528	10,112
Inverter costs	5,614	22,456
Total system costs (NPC)	52,577	210,308
LCOE	0.29	1

Note: 1 Euro equals 4 Malaysian Ringgit (RM).

Table 3
Top 4 solutions for PV–wind–battery system in Kampung Opar.

Solotions	Emission CO_2 (kg/yr)	NPC (€)	LCOE (€/kW h)	Annual load energy (kW h/yr)	Annual PV energy (kW h/yr)	Annual wind energy (kW h/yr)	Annual battery energy (kW h/yr)	Excess energy (kW h/yr)
1	641	52,577	0.29	7,181	11,282	1,582	4,167	4,505
2	700	53,253	0.30	7,181	11,282	1,582	4,168	4,505
3	706	53,393	0.30	7,181	11,421	1,582	4,168	4,643
4	778	56,151	0.32	7,181	14,666	1,582	4,167	7,887

using hybrid system in Malaysia can be cost effective and reduce the maintenance problems.

3.2. Islands of Mersing in Johor (PV–diesel)

Baharudin et al. [48] discussed about various aspects such as cost and configuration of implemented hybrid project in remote islands located off Mersing district in Johor. The authors suggested utilization of more HRES for future in remote areas with lower operation and maintenance cost for long term.

3.3. Orang Asli settlements in Peninsular Malaysia (PV–wind–diesel)

This hybrid system is installed in Orang Asli village of Kampung Denai in Rompin, Pahang by TNB [49].

3.4. Pulau Kapas (PV–diesel)

The hybrid system in Kepas island is launched by TNB and Terengganu Government [49].

3.5. Pulau Perhentian (wind–solar)

Darus et al. [28] discussed about the implementation and specification of installed hybrid renewable energy system in Perhentian Island. The authors recommended more development and research in this field.

4. Proposed electrical applications

Kampung Opar village with latitude of 1.44 and longitude of 110.074 is located 34 km far from Kuching in Sarawak. The evaluation of this village is estimated 81 above the sea level [50]. This village is selected as study case because some people in this area do not have electricity [51].

Power consumption for a rural house in Malaysia, especially in Sarawak and Sabah is based on simple appliances. The people in such areas need some basic home electric appliances like lighting lamp, refrigerator, TV, fan etc for their houses and some other equipment for school and agriculture purposes as shown in Table 1.

To estimate the energy consumption, a formula is used [52] as below:

(Wattage $\times$ Hours used per day) $\div$ 1000 $=$ Daily kilowatt-hour (kW h) consumption (3.20).

5. Results and discussion

The combination based on the previous works is assumed to be PV–wind and battery for Malaysia. Therefore, in this section, a hybrid system with PV–wind–battery is designed for rural electrification purpose in Malaysia.

The iHOGA tool is used for this research. iHOGA (latest version of HOGA) which is developed by Dr Rodolfo Dufo-Lopez, is an

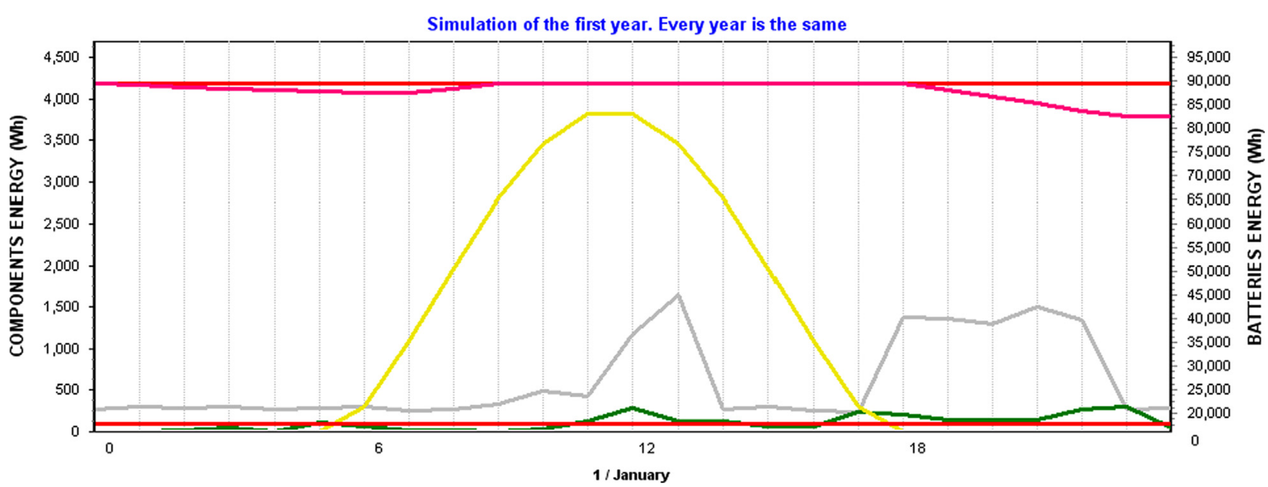


Fig. 6. Simulation of one day for PV–wind–battery system in Kampung Opar. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

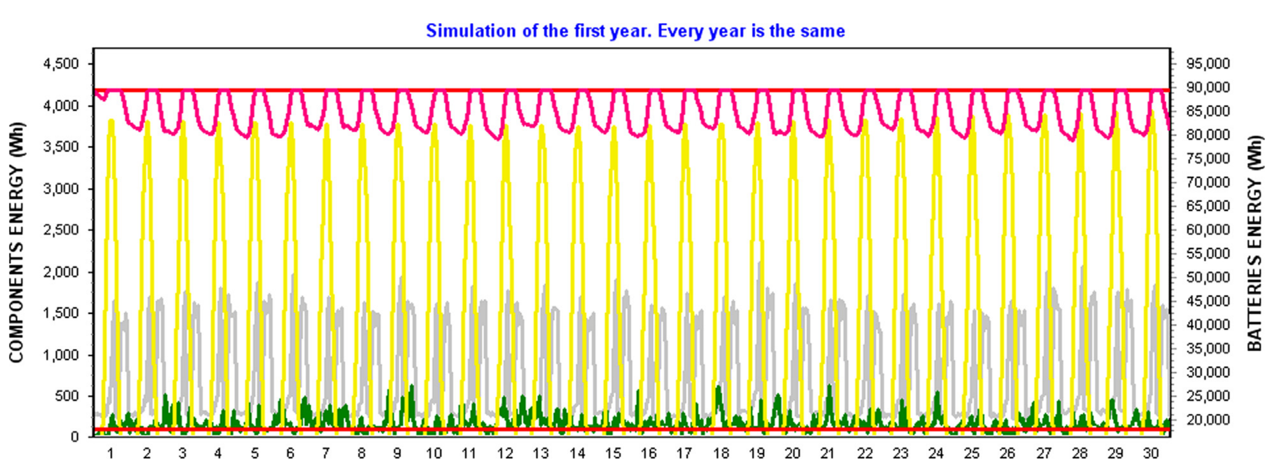


Fig. 7. Simulation of one month for PV–wind–battery system in Kampung Opar.

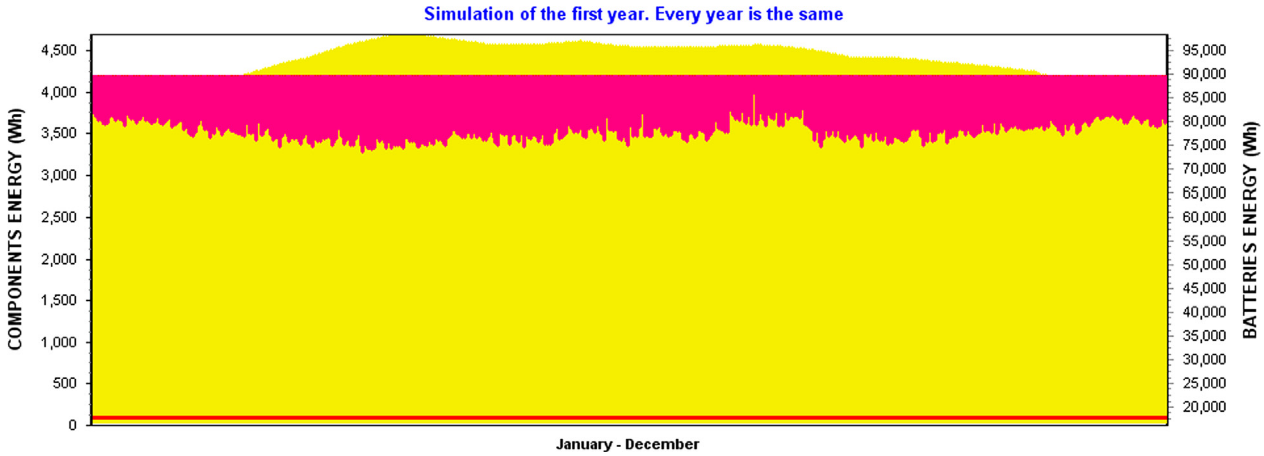


Fig. 8. Simulation of one year for PV–battery system in Kampong Opar.

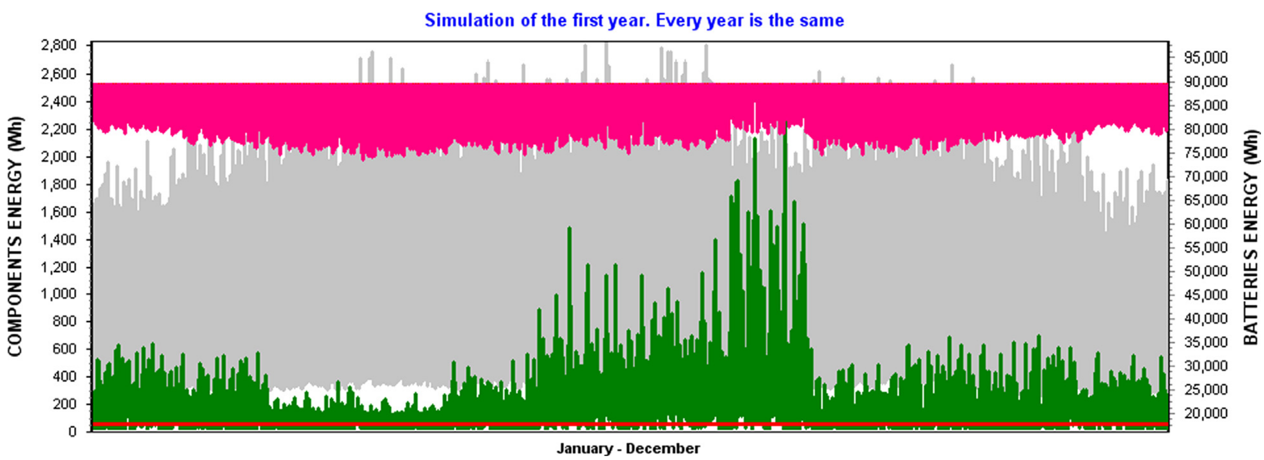


Fig. 9. Simulation of one year for PV–battery system in Kampong Opar.

accurate software in optimization of hybrid renewable energy systems [53].

The optimized number of PV panels, wind turbines and batteries are defined as shown in Table 2.

With this number of components, cost analysis and four possible solutions are suggested as shown in Table 3. The best solutions of sizing optimization are considered according to the lowest cost.

Estimated cost of energy per kW h (LCOE) has been one of items that are roughly comparable. LCOE is calculated about RM 1 for all study cases in this work. This amount as compared to available tariff rates in Malaysia for energy from national grid is around three times higher. The tariff rate is defined as 34 sen/kW h in Sarawak by Sarawak Energy [54]. The cost analysis of proposed hybrid system is provided in Table 4.

The simulation results for one day, one month and one year for PV system and wind–battery system in Kampung Opar are illustrated in Figs. 6–9. The PV and wind systems are shown separately for clear and better simulation results.

Graph in yellow shows the PV panels, wind turbines in green, SOC limits in red, SOC in pink and total load in gray. As shown in Fig. 6, although both solar and wind in the morning and at night have not been able to meet the total load, however, state of charge (SOC) in battery is high and the load is able to be supported. The SOC is increased by charging battery and decreased by discharging. When the charging and discharging do not happen due to self-discharge characteristic of battery, the SOC is decreased.

As illustrated in Fig. 8, although in one month the level of power produced by PV generator is higher than total load, however this generated power is intermittent because solar energy is not available during the day. Moreover, when the solar energy is at the peak, the energy of battery is at the highest rate.

The wind energy in all villages is lower than solar as explained in the last section. In this paper, wind energy is used as a supportive renewable source of energy in a small scale project.

6. Conclusion

As the main finding of this article, the rural electrification using hybrid renewable energy system has been introduced as a reliable solution in recent years for villages without electricity in the world. In Malaysia, the research and utilization of these systems have been started in a few previous years. Furthermore, the popular combination of HRES in previous studies for Malaysia has been the PV–wind–battery which is completely renewable.

Although the establishment of HRES depending on the weather condition and availability of energy sources, investigating the best combination of this system for new place is always a new challenge and directly will become promising research area for further exploration. Design and optimization of HRES for a village in Malaysia by using the proposed combination shows that this system could be cost effective.

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